Proton Irradiation of the 16GB Intel Optane SSD

E.J. Wyrwas[1]

NASA Goddard Space Flight Center
Code 561.4, Radiation Effects and Analysis Group
8800 Greenbelt RD
Greenbelt, MD 20771

Test Date: 4 Nov 2017
Report Date: 6 Nov 2017

[1]LENTECH Inc, Greenbelt, MD USA

I. Acronyms

BGA	Ball Grid Array (package type)
DUT	Device Under Test
GB	Gigabyte (memory storage capacity)
NEPP	NASA Electronic Parts and Packaging Program
NVME	Non-Volatile Memory Express
NWMCPC	Northwestern Medicine Chicago Proton Center
PCIE	Peripheral Component Interconnect Express bus
PCM	Phase Change Memory
SEE	Single Event Effects
SEFI	Single Event Functional Interrupt
SSD	Solid State Drive

II. Introduction

The purpose of this test is to assess the single event effects (SEE) and radiation susceptibility of the Intel Optane Memory device (SSD) containing the 3D Xpoint phase change memory (PCM) technology. This test is supported by the NASA Electronics Parts and Packaging Program (NEPP).

III. Devices Under Test

The Intel Optane Memory SSD uses Intel and Micron's ovonic phase change memory technology which uses chalcogenide materials for both the selector and storage parts of the memory cell. This technology is fabricated at 20nm. This is the first generation of Intel's device and is available in 16GB and 32GB capacities.

Figure 1: Intel Optane Memory SSD

Cross sectioning analysis was conducted. It is worth noting that this device is wire-bonded from the top side. For orientation within the radiation beam, a top-side exposure would permit the most direct path to the active region within the die. It is expected that higher capacity devices will be multiple 16GB die stacked in a cantilever configuration. Therefore, it can be said that testing results collected for the 16GB device is representative of the others within the generation.

There are other active components on the SSD aside from the Xpoint. We only targeted the Xpoint chip in this test. The SSD specifications and features can be found on Intel's website [i]. Basic device and test information is provided in Table I.

Table 1: Intel Optane Memory SSD - Device Information

REAG Part Number:	17-045
Generic Part Number:	MEMPEK1W016GA
Manufacturer:	Intel
Lot Date Code (LDC):	Unknown
Quantity Tested:	4
Part Function:	Solid state drive
Part Technology:	3D Xpoint – 1st generation
Case Markings:	Model: MEMPEK1W016GA
Package Style:	BGA on M.2 22 x 80mm
Interface:	PCIe NVMe 3.0 x2
Test Equipment:	Power Supply (+5V, +3.3V), Linux PC

IV. Test Facility

The testing will be carried out using the proton source at Northwestern Medicine Chicago Proton Center (NWMCPC).

Spot size: 1 x 1 inch^2
Energies: 200 MeV
Flux: 1e7 to 1e8 p+/sec

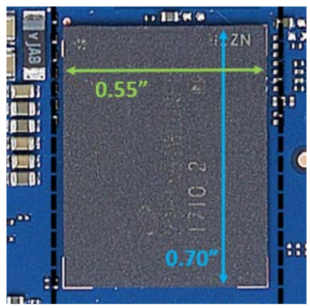

Figure 2: Size of Memory Device Package

V. Test Method

A. Device characterization

We utilized an open source software called “Caine” as the diagnostic tool to perform read and write operations to the SSD [ii]. We used a 64-bit Ubuntu 14 Linux environment to run a collection of tools, including pipe viewer, 7-Zip archiver, a hash calculation tool, and “dd” (convert and copy tool), with its derivatives dcfldd, dc3dd.

A lab bench power supply which was separate from the PC provided power to the SSD. The power supply allowed examination of the SSD’s supply current using a LabVIEW program called Continuous Power Supply Monitor created for NASA Goddard’s Radiation Effects and Analysis Group.

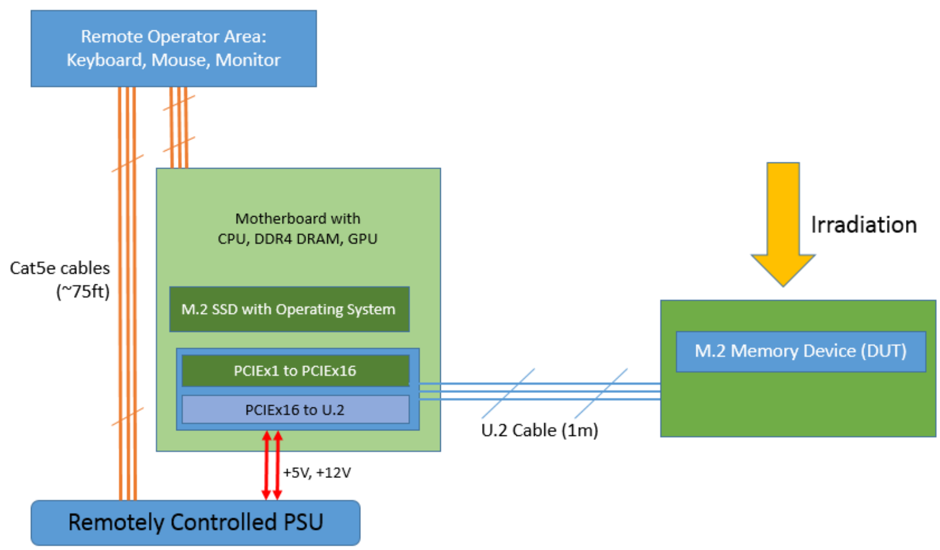

Figure 3: Test Setup Configuration

B. Irradiation procedure

There were two sets of bias conditions under investigation – Static and Dynamic. In the static case, the DUT was programmed with a known pattern (AA, 55, 00 or FF). The DUT remained in standby mode during irradiation. At irradiation down points, we performed diagnostic tests, which measured basic device functionality and data fidelity. If data corruption errors existed from the "check bad blocks" read, an image read was necessary to capture the errant bytes. Then the DUT was erased, and reprogrammed with an inverse pattern (e.g. AA to 55 or FF to 00). Then the DUT was programmed with the next pattern and irradiated again.

In the dynamic case, the DUT was programmed with a pattern or read from during irradiation. The characterization procedures at irradiation down points was identical to the previous "static" condition. The procedures are detailed below.

The irradiation continued until the DUTs were nonfunctional or showed severe performance degradation (e.g. significant reduction in read or write speed).

The test procedure was as follows:

1. Pre-irradiation:
   a. Record the position (distance) of the source relative to the DUT surface; alternatively, record the dose rate.
   b. Ensure normal functionality and performance after the device is set up in the configuration ready for exposure
   c. Measure and record the SSD supply current during standby, and read/write cycle
2. Write 1st pattern to entire SSD prior to irradiation
3. Exposure
   a. Irradiate with device in standby mode
   b. Or, irradiate with device in continuous write/read cycle
4. At irradiation down point, read the entire memory space and capture image
   a) Perform a second read to examine whether some errors can be cleared
5. Erase using the quick erase function
6. Reprogram SSD to 2nd pattern

7. Irradiate to the next dose step
8. Repeat from step 3 until device is nonfunctional or show significant performance degradation.

Table 2: Test Sequence for all DUTs

Payload	Type	Sub-Type	Pattern
Static_AA	Static		AA
Static_55	Static		55
Static_00	Static		00
Static_FF	Static		FF
DynWr_AA	Dynamic	Write	AA
DynWr_55	Dynamic	Write	55
DynWr_00	Dynamic	Write	00
DynWr_FF	Dynamic	Write	FF
DynRd_AA	Dynamic	Read	AA
DynRd_55	Dynamic	Read	55
DynRd_00	Dynamic	Read	00
DynRd_FF	Dynamic	Read	FF

C. Test conditions

Test Temperature: Ambient temperature
Operating Frequency: Statically biased during irradiation
Power Supply: 12V, 5 V
Parameters: 1) Supply voltage
2) Supply current
3) Errant byte

VI. Results

Each run was performed over a 100 second duration. The flux was increased from 1e7 to 1e8 p+/sec after the first two DUTs were tested. It is worth noting that a trend in electrical parameters has started to emerge within the data when comparing nominal non-radiative values to those corresponding to SEFI occurrences. Nominal current draw during read/write is typically 120-140mA. Above 140mA, the devices would lock the system out from future read/writes after the programming event finished. For all such occurrences, the programming events completed successfully. At idle or standby, the device tends to draw approximately 75mA. In runs where the device became unresponsive after programming, the idle draw was approximately 82mA.

No anomalous activity took place during the irradiation. In each static test, the DUT did not experience any bit errors as reported in the system. For each dynamic test, the DUT performed its task during irradiation without incident. However, after some of the programming events and after the radiation was stopped, the device would become unresponsive. To troubleshoot, first the DUT was power cycled, then the DUT and complete tester system. In all cases, the DUT was unresponsive until the tester system was reset. Two scenarios need to be further proven out to determine the cause. First, we have not performed in-situ temperature monitoring of the 3D Xpoint device during irradiation. The device's firmware parameters suggests that it has a hard-lock out at 80°C (which differs from the datasheet which says 85°). Second, it is possible that the microcontroller on the DUT was also being irradiated due to the geometric shape of the spot size.

Table 3: SEE Test Results for Intel Optane

Run #	Payload	fluence	flux (p+/sec)	suggested bit error	cross section	crash condition	notes
4	#1_Static_FF	9.62E+08	9.62E+06	1	1.04E-09	SEFI	tester restarted; device remains non-functional
17	#2_DynWr_AA	9.82E+08	9.82E+06	1	1.02E-09	SEFI	after reset, device behaved nominally
18	#2_DynWr_55	9.59E+08	9.59E+06	1	1.04E-09	SEFI	in 140mAs during write; after reset, device behaved nominally
23	#2_DynRd_00	6.88E+08	6.88E+06	1	1.45E-09	SEFI	possible temp excursion; after reset, device behaved nominally
28	#3_Static_FF	1.03E+10	1.03E+08	1	9.71E-11	SEFI	in 140mAs during write; after reset, device behaved nominally
29	#3_DynWr_AA	1.10E+10	1.10E+08	1	9.09E-11	SEFI	in 140mAs during rad; possible SEFI @ 71% write cycle after reset, device behaved nominally
30	#3_DynWr_55	9.00E+09	9.28E+07	1	1.11E-10	SEFI	elevated idle current at 82mA after reset, device behaved nominally
				average	6.93E-10		
				minimum	9.09E-11		
				maximum	1.45E-09		

VII. Summary

This test was the first in a series to determine the radiation susceptibility of Intel's 3D Xpoint memory technology. Four (4) 16GB Intel Optane SSDs were tested under a variety of data transfer conditions. This test did not expose any clear trends in regards to pattern dependence for programming these devices and subsequent quantities of bit flips. While no bit flips occurred, several SEFIs did, which is indicative of a possible secondary failure mode which may be driving these events. It may be possible to detect an upcoming SEFI event through current monitoring of the device.

[i] https://ark.intel.com/products/97544/Intel-Optane-Memory-Series-16GB-M_2-80mm-PCIe-3_0-20nm-3D-Xpoint
[ii] http://www.caine-live.net/